AD-A117 014 ARMY MISSILE COMMAND REDSTONE ARSENAL AL GUIDANCE A--ETC F/G 11/9
HIGH-G PLASTIC MATERIAL INVESTIGATION.(U)
MAR 81 A RODGERS
UNCLASSIFIED DRSMI/RG-81-19-TR SBI-AD-E950 263 NL

END
DATE
FILMED
8-82
DTIC

AD-E950263

12

AD A117014

TECHNICAL REPORT RG-81-19

HIGH-G PLASTIC MATERIAL INVESTIGATION

Aubrey Rodgers
Guidance & Control Directorate
US Army Missile Laboratory

March 1981

U.S. ARMY MISSILE COMMAND

Redstone Arsenal, Alabama 35809

Approved for public release; distribution unlimited.

DTIC
ELECTE
JUL 16 1982
S D
B

DTIC FILE COPY

82 07 16 001

DISPOSITION INSTRUCTIONS

DISCLAIMER

TRADE NAMES

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-RG-81-19	2. GOVT ACCESSION NO. AD-A117 014	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) High-G Plastic Material Investigation		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Aubrey Rodgers		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander, US Army Missile Command ATTN: DRSMI-RG Redstone Arsenal, Alabama 35898		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Commander, US Army Missile Command ATTN: DRSMI-RPT Redstone Arsenal, Alabama 35898		12. REPORT DATE March 1981
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Monomers, polymers, copolymerization, thermoplastics, thermosetting, reinforcing fillers, extrusion molding, injection molding, transfer molding, compression molding

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this task is to identify and select plastic materials which are suitable candidates for molded high-g inertial instrument subcomponents. The report discusses the selection factors, requirements and criteria used in choosing promising candidates for further analysis. A program is outlined which defines the work required to develop reliable data on molded strength properties fabrication and assembly methods. Experience must be gained to design successful plastic parts; parts that perform reliably over an acceptable time period and

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED (over)

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. (Continued)

that can be produced, finished and assembled at an economical cost.

CONTENTS

I. INTRODUCTION

The term "plastics" usually refers to a class of synthetic organic materials which, though solid in the finished form, at some stage in their processing are fluid enough to be shaped by application of heat and pressure. Plastics in finished form consist of long chain polymers, which are built by combining single monomers under heat and pressure. Cross-linking of two or more polymers, a process analogous to alloying in metals, is known as copolymerization. There are two basic types of plastics: thermoplastics which may be softened and resoftened repeatedly without undergoing a change in chemical compositions; and thermosetting resins which undergo a chemical change with application of heat and pressure, and cannot be resoftened.

The choice of plastics includes thousands of available types and formulations. There are many distinct families of plastics and within each family there are many different types. Each type can be produced in a variety of different forms having different properties within a given range. Although the diversity of plastics is great, in practice the choice for a given application will lie within a relatively narrow band of the materials spectrum.

II. SELECTION FACTORS

The designer should consider not only the physical, chemical, optical, and electrical properties, but also the cost and method of processing. Often the question of how a product is to be processed or the environment determines the type of material to be selected. The key to selecting the right plastic is good communication between the designer, processor and material supplier.

The more rigid the specifications covering end-use, the easier the choice becomes. If, for instance, the prime requirement is light-weight, high strength, high impact resistance and wide temperature range, the problem of selection is reduced to a few plastic types. Trial and error as a means of selection is exceedingly costly and, therefore, careful study of the problem is warranted. If the specifying designer understands the requirement, there probably is a good compromise among highest performance, efficient production, and lowest cost. Achieving the best compromise requires satisfying the mechanical requirements of the part, utilizing the most economical plastic that will perform satisfactorily, and choosing a manufacturing process compatible with the part design and material choice. Setting a realistic requirement for each of these areas is of utmost importance.

III. APPLICATION REQUIREMENTS

A plastic material for a low cost, high-g inertial instrument or a stabilized gimbal platform carried by a high velocity projectile is a desirable requirement for future applications. The objective of this task is to study and select the right plastics that will perform properly and safely in the environment.

The rationale used in the selection criteria is based on the following primary material requirements:

o The structural support material for an inertial instrument must be low

cost, support a sensor element weighing at least two kilograms, and have a high probability of surviving a 12,000 g launch longitudinal load, a concurrent 800 g transverse peak launch acceleration and a reverse load of 1,000 g's.

o The material must support an instrument that fits within the size and shape of a 155 millimeter envelope.

o The structural support material must meet applicable thermal and environmental MIL-STD specifications.

o Cost effectiveness of the material, processing and assembly must be an equal performance parameters, a major criterion for the subsequent studies.

IV. SELECTION CRITERIA

A. General

There is no simple procedure for selecting the best plastic for a new application. It must be done with direct experience and knowledge of the behavior of plastics under the actual conditions encountered by a particular part after it is molded. Until one can acquire this knowledge, one has little choice but to use the many qualitative and quantitative tables that exist in available handbooks, periodicals and other technical literature. The significance of this data is limited by the fact that ASTM or UL tests are conducted under standard conditions, while the service properties of plastics are markedly affected by variations in temperature, loading rate, time, environment, compounding and processing. However, these ASTM or UL values, when properly interpreted and correlated with individual plastic behavior, can aid in determining the best plastic for the application by comparing the relevant properties of each material.

These properties are divided into mechanical, thermal, electrical, physical, effects of environment, and processing categories which are discussed in the subsequent paragraphs.

B. Mechanical Properties

1. General

The physical capabilities of plastics are deduced from stress-strain curves obtained by loading test pieces of the material in tension, compression and shear. The stress-strain curve is employed for evaluating five basic properties - stiffness, resilience, elasticity, strength and toughness. Two distinct regions of the stress-strain curve are important in design work; the Hook's law linear region (the proportional limit) and the region around the yield point (the elastic limit). For stresses up to the yield point, the material is ideally elastic; that is, the strain disappears on release of the stress. Beyond the yield point, the material is no longer an elastic body but is behaving as a plastic solid. After yield point, an increase in stress is required to effect further elongation until a failure (the break tensile strength). If the stress is removed after the yield point and before failure, the material will have a permanent set.

2. Tensile Modulus

Stiffness or tensile modulus is considered to be the most important single indication of strength in a material. It is the ratio of applied stress to resultant strain below the proportional limit of the material. Tensile modulus data should be viewed in conjunction with elongation values to achieve the right proportion of resilience and brittleness. Parts should be designed to accommodate stresses to a degree well below the proportional limits.

3. Elongation

The elongation of a material is the amount of increase in length resulting from tension required to break a specimen and is expressed in terms of percentage of the original length. There is great benefit in moderate elongation since this quality permits absorbing rapid impact and shock.

4. Resilience

Resilience is evaluated by the area under the elastic portion of the stress-strain curve. This area represents the work required to deform the material to its elastic limit, or the energy that the material can absorb without undergoing permanent deformation.

5. Tensile Strength

Elasticity or yield tensile strength is the stress at the yield point. For plastics, the yield strain is of great significance because it has the ability to carry stress without suffering permanent set. Break tensile strength is a measure of the force necessary to pull the specimen apart. Some plastics fail by yielding, some by breaking thus giving rise to two variants of tensile strength. Tensile strength is the ability to carry dead weight and it is dependent on temperature and rate loading. A plastic of very high tensile strength and little elongation would tend to be brittle in service.

6. Toughness

Toughness is evaluated by the total area under the stress-strain curve. It is the total work that must be done to rupture the material. When the total work to effect rupture is low, the plastic is said to be brittle. Toughness is not related to any particular rate of loading.

7. Impact Strength, Izod

The impact resistance is the ability of a material to resist breaking under a shock loading or a stress delivered at a high rate of speed. The Izod impact test indicates the energy required to break a specimen in which there is a "V notch" to create an initial stress point. The breaking stress is applied suddenly, as contrasted with the tensile test in which it is applied continuously. Though a very useful indicator of overall toughness or impact strength, it cannot be used in a totally absolute way because some materials are notch-sensitive. This value may indicate the need for avoiding sharp corners in parts made of notch-sensitive materials. For example, nylon, which in molded parts are among the toughest plastics, is notch-sensitive and registers relatively low values on the notched Izod impact test.

8. Notch-Sensitivity

Notch-sensitivity is an important factor to be considered. It is defined as the ratio of the strength of an unnotched sample to that of a notched sample of equal depth behind the notch.

9. Flexural Modulus

Flexural modulus is the ratio, within the elastic limits, of the applied stress on the test specimen to the corresponding strain in the outermost fibers of the specimen. The applied stress is defined during a bending or flexing cycle, where the specimen is supported at two points with the stress being applied midway between them.

10. Flexural Strength

Flexural strength is a measure of the resistance of a material to fracture during bending. Tests for flexural strength are carried out by having the plastic supported at two points, with the downward load being applied midway between them. Most thermoplastics do not break in this test - instead, stress at 5% strain is calculated - that is, the loading necessary to stretch the outer surface 5%. An important factor to be considered is the effect of notch-sensitivity on the flexural strength of the material. Consider two plastics with flexural strengths of 20,000 and 16,000 psi, respectively. Assume the respective notch-sensitivities to be 2.0 anc 1.0. The effective flexural strength in a member will then be 10,000 psi for the first material and 16,000 psi for the second material. Therefore, the importance in respect to design such as holes, threads, angles and notch effect contributions to flexural strength weakness is obvious.

11. Compressive Strength

Compressive strength is the ability of a material to resist a force that tends to crush it. Its value is given by the compressive load at the failure of a specimen divided by the original area of the specimen.

12. Hardness

Rockwell hardness is a measure of the resistance to indentation, not of surface hardness. The various Rockwell scales are designated by letters to indicate the indenter size and the applied load. The hardness values are arbitrary numbers having an inverse relationship to the depths of the indentation. The Rockwell M scale is used for harder materials and the R scale is used for softer materials.

Rockwell values can differentiate relative hardness of different types of plastics. But since elastic recovery is involved as well as hardness, it is not valid to compare hardness of various kinds of plastics entirely on the basis of the harness value.

Rockwell hardness is not an index of wear qualities or abrasion

resistance. For example, some plastics have high Rockwell hardness values but poor wear resistance.

13. Creep

Plastics are subject to a phenomenon known as creep or cold flow. Most plastics experience slow changes in physical characteristics with usage or over long periods of time. These changes result in slight deformations that may effect the application of the original part. Creep is the temperature and time-dependent strain of a material under stress. Though an important property to consider in product design, creep modulus data is not commonly reported due to the length of time required to test each material.

14. Reinforcing Fillers

A reinforcing filler is generally used for additives that enhance various physical, electrical and thermal properties of a plastic and its end product. Reinforcing fillers are fibrous and increase stiffness, strength, impact resistance and hardness.

C. Thermal Properties

1. Continuous Service Temperature

Continuous service temperature is the highest temperature at which a plastic can perform reliably in a long-term application. It is a particularly valuable number to know as most plastics ultimately fail in service because of long-term temperature effects that cause polymer degradation.

2. Brittleness Temperature

Brittleness temperature is of some use in judging the relative merits of various materials for low temperature flexing or impact. It is specifically relevant only for materials and conditions specified in service and the values cannot be directly applied to other shapes and conditions. The brittleness temperature does not put any lower limit on service temperature for end-use products. The brittleness temperature is sometimes used in specifications.

3. Linear Thermal Expansion

Linear thermal expansion is the change in length of a material for a unit change in temperature. Plastic materials often change in length and volume because of changes in moisture content, curing, loss of plasticizer, release of stress, etc. This value is designed to exclude all other influence except changes in dimension due to thermal expansion. This property is a good indication of the behavior of a plastic in molding, i.e., of the linear mold shrinkage.

4. Thermal Conductivity

Thermal conductivity is a measure of the heat flow through a material; a high value meaning a good heat transfer agent, a low value meaning a good thermal barrier.

5. Specific Heat

Specific heat is essential in calculating insulating values. It is part of the parameter generally known as thermal diffusivity, which governs the rate of temperature diffusion through insulation. Its value depends upon chemical composition and temperature.

6. Deflection Temperature

Deflection temperature is the temperature at which an arbitrary amount of deflection occurs under established loads. It is not intended to be a direct guide to high-temperature limits for specific applications. It may be useful in comparing the relative behavior of various materials.

7. Flammability Class

Flammability is a significant property of plastic materials. The flammability test description gives standards for deciding when the material supports combustion. This standard should be used to measure and describe the properties of a material in response to heat and flame under controlled laboratory. Materials may be classified based on test conducted in compliance with Underwriters Laboratories Inc. Standard Tests for Flammability of Plastic Materials. Flammability Class 94 V-0 in thickness of 0.125 inches and greater meets industry codes for electrical machines, aircraft, and safety equipment.

D. Electrical Properties

1. Volume Resistivity

Volume resistivity is the resistance offered by the conducting path to the passage of electric current. The higher the value, the better for a good insulating material. The resistance varies inversely with temperature and is affected by humidity, moisture content and the level of the applied voltage.

2. Dissipation Factor

Dissipation factor is the ratio of the power dissipated in an insulating material related to the product of the effective voltage and the current. It is a measure of the relative dielectric loss in an insulating material when the system acts as a capacitor. This dimensionless unit is of particular interest in high levels of frequency and power. Generally, low values are favored because they indicate a more efficient system with lower power losses.

3. Dielectric Constant

Dielectric constant is the ratio of the capacitance of a capacitor filled with that particular material to the capacitance of the same electrical system with air or a vacuum replacing the insulation as the dielectric medium. Low values are best for high-frequency or power applications to minimize electrical losses. Higher values are best for capacitance applications.

4. Dielectric Strength

Dielectric strength is the voltage that an insulating material can withstand before dielectric breakdown occurs. The higher the value, the better the insulator. The dielectric strength of a material generally increases sharply with a decrease in insulation thickness.

5. Arc Resistance

Arc resistance is the time, in seconds, that a surface may be exposed to a high voltage-low current arc before electrical breakdown occurs. Arc resistance of plastics vary widely depending on their molecular structure and formulation. Fillers have a pronounced effect, generally improving the arc resistance.

E. Physical Properties

1. Density

Density is the mass of a substance per unit volume. A lightweight material is desirable for high-g applications.

2. Water Absorption

The water absorption value is a measure of the percentage gain in weight after 24 hours of immersion. Water absorption affects plastic properties in various ways causing electrical property variations, crazing, cracking, dimensional instability etc.

3. Chemical Resistance

Chemical resistance data is useful in choosing candidate materials for service testing. The collection of chemical resistance data is difficult because of the diversity of reagents to which resin suppliers choose to expose their materials. Conditions of concentration, temperature, stress and time are not standardized.

A selection of some common agents as shown in Table II presents comparative information. The descriptive words - poor, fair, good and excellent - are used to give a generalized assessment of supplier's information and other technical sources. Interpretation of comparative ratings follow:

o Poor. The use of the plastic in the presence of the indicated agent is not recommended.

o Fair. The use of the plastic is marginal in these environments and may be considered for short exposures at lower temperatures and in situations where appreciable loss of mechanical properties is not critical.

o Good. The use of the plastic is quite acceptable in ordinary exposure to the particular agent. Long term exposures may result in some minor loss of properties, but exposures at elevated temperatures may result in significant property losses.

o Excellent. The use of the plastic is unaffected by the reagent and compares similarly to unexposed material in its acceptable performance with regard to time, temperature and stress.

The comparative information presented in Table II takes into consideration the environmental and stress cracking tendencies of the material.

F. Effects of Environment

Physical properties of plastics are temperature sensitive. In general, as temperature increases, stiffness, strength and fatigue life decreases. Conversely, impact strength, creep and stress relaxation increase with increasing temperature. While many plastics cannot be used at temperatures below minus 40°F, a few specifically designed formulations attain their maximum strength below this value. However, the overall effect that temperature has on plastics depends on both the specific environment and the load to which the component is subjected. Design data used for the material must conform to the application requirements.

Water absorption and temperature can cause dimensional instability. Some materials absorb considerable moisture in atmospheric service resulting in both dimensional and property changes. These factors are significant in designs which combine several materials in an assembly.

G. Processing Methods and Material Behavior

1. Molding

Plastics may be molded by one of several processes: extrusion, injection, transfer, and compression. Generally, thermoplastics are used for extrusion and injection molding, and thermosetting resins are used for transfer and compression molding.

o Extrusion molding consists of forcing hot melted thermoplastic material through a die of the desired cross section to produce the part. A disadvantage of this process is that close tolerances are difficult to obtain.

o Injection molding consists of a thermoplastic, in granular form, heated to plasticity in a cylinder, then injected under pressure (about 2,000 psi) to a closed temperature-controlled mold. The molded piece, upon cooling, is removed from the mold as soon as it is rigid enough to handle and the molding cycle is then automatically repeated. Injection molding is a high-rate production process with resultant low cost per part. Metallic inserts can be molded in at slight additional cost. Little finishing is required and the process produces good dimensional accuracy. Injection molding is capable of producing parts of relatively intricate configurations.

o Transfer molding is a variation of injection molding for thermosetting plastics. The material in powder or pellet state is heated to plasticity in a transfer chamber. It is then transferred under pressure (100 to 200 psi) through sprues and runners into a closed mold where polymerization is completed. Transfer molding offers several advantages: Thin sections and delicate inserts can be used. Flow of material is controlled easily. Dimensional accuracy is good. Production rates are rapid.

o Compression molding consists of a cavity mold filled directly with thermosetting resin; heat and pressure are applied until the resin melts and fills the cavity. This process has little waste of material and has low finishing costs. Extremely intricate parts such as undercuts, small holes, and delicate inserts are not practical. Close tolerances (+0.005 in. or less) are difficult to achieve.

2. Linear Mold Shrinkage

Linear mold shrinkage is the initial shrinkage of a material upon fabrication, not the shrinkage after a specified first time period. The shrinkage is the ratio for the difference between the size of the part and the size of the mold cavity. If linear mold shrinkage cannot be determined, linear thermal expansion is a good indication of the materials behavior.

H. Part Finishing and Assembly Techniques

1. In addition to the combination of good properties possessed by plastics, they can be easily finished into end products by a variety of indicated processes. Careful design of molded plastic parts can simplify or eliminate many finishing operations. However, most molded plastics require some finishing, if only to remove flash lines and gates or to improve surface texture. Filing, tumbling, sanding, buffing, polishing, and transparent coating are the most commonly used methods.

2. Data on machinability of plastics are limited. The primary processing method generally yields end-products that are usable as is, and very little work has been done to develop precise information on the full range of generic plastics for the full range of machining operations. Most of the publishable data on machining of plastics has been produced by the Machinability Data Center, Cincinnati, Ohio. This Center is operated for the U.S. Department of Defense Supply Agency by Metcut Research Associates, Inc.

3. Plastics, with their inherently different properties, cause several difficulties in machining such as:

o Plastics' coefficient of thermal expansion is roughly an order of magnitude greater than metals'.

o Plastics' thermal conductivity is substantially less than metals'.

o Plastics' operating temperatures are much lower than metals'.

o Plastics' elastic modulus is about 1/25th that of metals.

o Plastics' elastic recovery is great.

As a consequence of these differences, problems of heat dissipation, tool clearance, tool materials, tool angles and machine speeds need considerable experimentation and adaptation to achieve optimum results.

4. In many applications, the economy of the part may be in proper use of assembly techniques. However, assembly methods are not the whole story; the part must be designed for assembly. Low cost assembly processes must take advantage of mass-production requirements. This includes design simplicity of assembly, minimum number of assembly operations and automated component in-line assembly methods.

5. The plastics industry is still relatively young and has not yet developed reliable data on molded strength properties, fabrication and assembly methods. Experience must be gained to design successful plastic parts; parts that perform reliably over an acceptable time period and that can be produced, finished and assembled at an economical cost.

V. SELECTION OF MATERIALS

A. Screening

The objective of this task is to screen and select plastic materials suitable for the development of a low cost inertial instrument which must survive a high-g launch. Thousands of plastics are commercially available with diverse properties ranging from general purpose materials to highly specialized formulations. In order to narrow the field to a manageable number, selection criteria in Section IV were used. Published articles in open literature, handbooks and ASTM data were used to identify nine possible materials for this application, Tables I, II. These selected generic types are:

- Epoxy Cycloaliphatic
- Melamine Formaldehyde
- Poly(amide-imide)
- Polyimide
- Polyphenylene Sulfide

B. Discussion of Advantages/Disadvantages

1. Epoxy Cycloaliphatic

Epoxies are available in a wide variety of formulations and curing-agent variations. Thermosetting epoxies are based on polyglycidyl resins that are cured by either of two methods: homopolymerizing and copolymerizing. The copolymerizing contribute significantly to the properties of the cured materials. The bisphenol A type are the most frequently used epoxies. They provide excellent electrical and mechanical properties, heat resistance, dimensional stability and adhesion to most materials. The cycloaliphatic epoxies are gaining in use and offer good physical properties and arc resistance in addition to the properties of the bisphenol A type. The cycloaliphatic types have been produced which are synthesized by the epoxidation of the corresponding olefin, usually by peracetic acid. They differ from glycidyl ether types in that amine cures are usually not suitable and they are polymerized by anhydride cures.

Epoxies are conveniently cured and no voltiles are formed during their cure. They have exceptional mechanical strength and excellent adhesion. They are somewhat moisture sensitive and have poor oxidative stability; thermal stability is limited to 350-450°F. Strength is increased when the resins are compounded with reinforcing fibers. Maximum stengths are obtainable with certain cycloaliphatic resin types.

Molded parts are hard, rigid, relative brittle and have excellent dimensional stability over a broad temperature range. Some fiber-reinforced composities can withstand service temperatures above 500°F for short periods.

In general, epoxies have excellent electrical properties. The bisphenol A types are adequate for most service; however, cycloaliphotic resins are recommended for arcing conditions.

Epoxies are highly resistant to caustic materials, many solvents and most acids. Fillers and reinforcements can either improve or degrade chemical resistance. Asbestos fiber is recommended for applications requiring maximum chemical resistance.

Advantages:

- Convenient range of cure conditions from room temperature to 350°F.
- No volatiles formed during cure.
- Varying degrees of properties depending on the hardeners used.
- Many filled grades available to provide tailored properties.
- Excellent adhesion.
- Suitable for all thermosetting processing methods.

Disadvantages and Limitations:

- Poor oxidative stability and some moisture sensitivity.
- Thermal stability limited to 350-450°F.
- Some epoxies outgas products or contain ions deleterious to electronic devices.
- Specialty formulations are comparatively expensive.

2. Melamine Formaldehyde

Melamine Formaldehyde are fairly inexpensive thermosetting resins and are frequently referred to as aminos or amino plastics. They are formed by condensation of melamine, urea or casein with formaldehyde, resulting in a highly crosslinked resin which is similar to a phenolic in utility. These thermosets have good hardness and scratch resistance, comparatively low cost and good solvent resistance. They must be filled for successful molding, their long-term oxidation resistance is poor and they are attacked by strong acids and bases.

Advantages.

- o Good hardness and scratch resistance.
- o Comparatively low cost.
- o Self extinguishing.
- o Solvent resistance, including hot water.

Disadvantages and Limitations.

- o Must be filled for successful molding.
- o Long-term oxidation resistance is poor.
- o Attacked by strong acids and bases.
- o Continuous service temperature limited to about 300°F or less.

3. Poly(amide-imide)

Poly(amide-imide) is an injection-moldable thermoplastic characterized by high strength and good impact resistance. It has high-temperature performance, excellent electrical and mechanical properties. Molded parts can maintain structural integrity in continuous use at temperatures to 500°F.

This thermoplastic material can be molded into precision parts in conventional, screw-injection molding machines. High injection speed, melt temperature of 630 to 675°F, and pressure of 20,000 psi or greater are desirable.

Radiation resistance of poly(amide-imide) is good; tensile strength loss is about 5% after exposure to 10^9 rads of gamma radiation. Chemical resistance is good, the material is virtually unaffected by aliphatic and aromatic hydrocarbons, halogenated solvents and most acid and base solutions. It is affected by high-temperature caustic materials, steam, and some acids.

Poly(amide-imide) absorbs moisture in humid environments.

Advantages.

- o Creep resistance is among the best of the thermoplastics.
- o Dimensional stability is extremely good.
- o Compressive strength is very good.
- o Good high temperature, chemical and radiation properties.

Disadvantages and Limitations.

- Some moisture sensitivity.
- Attacked by high-temperature caustic materials, steam, and some acids.

4. Polyimide

Polyimides are among the most heat and fire-resistant polymers known. Polyimides are members of the class sometimes referred to as hetroaromatics. Their excellent retention of mechanical and physical properties at high temperatures is due to the fused-ring nature of the aromatic raw materials that are building blocks of polyimides. Polyimide parts can operate continuously in air at 500°F; service temperature for brief exposure can range from cryogenic to as high as 900°F. Glass-fiber-reinforced formulations retain over 70% of their flexural strength and modulus at 480°F. Creep is almost nonexistent, even at high temperature and under load.

Electrical properties of polyides are excellent over a wide range of temperature and humidity conditions.

Chemical resistance of polyimides is excellent except they are attacked by dilute alkalies and concentrated inorganic acids.

Polyimides are comparatively high cost and dark in color. They are difficult to process and this disadvantage has reduced the extent of their application.

Polyimides are formulated as both thermosets and thermoplastics.

Advantages.

- Temperature capability of 600°F or 90°F for short duration.
- Excellent barriers.
- Excellent solvent resistance.
- Excellent adhesion.
- Especially suitable for composite fabrication.
- Creep almost nonexistent.

Disadvantages and limitations.

- Difficult to fabricate.
- Attacked by alkali.
- Comparatively high cost and dark in color.
- Most types have volatiles or contained solvent which must be vented during cure.

5. Polyphenylene Sulfide

The recently developed polyphenylene sulfide is a strong, high-temperature, chemical resistant thermoplastic. Ryton, its trade-name, is available in glass-fiber and mineral/glass-fiber-reinforced grades for injection-molding.

Polyphenylene sulfide has outstanding chemical resistance, good thermal stability, low water absorption, along with good electrical properties. Dimensional stability is excellent and shrinkage rate is low and predictable. Polyphenylene sulfide is high cost and difficult to process. It requires a processing temperature for molding in the range of 600 to 650°F.

Advantages

- Capable of extended usage at 450°F.
- Good solvent and chemical resistance.
- Good radiation resistance.
- Excellent dimensional stability.
- Non-burning.
- Low water absorption.

Disadvantages and Limitations

- Difficult to process, high melt temperature.
- Comparatively high cost.
- Fillers required for good impact strength.
- Attacked by chlorinated hydrocarbons.

C. Remarks

Thermoplastics generally offer higher impact strength, easier processing, and better adaptability to complex designs than do thermosets. In general, thermosets have better dimensional stability, heat resistance, chemical resistance and electrical properties than do the thermoplastics. Most thermosets are principally in filled and/or reinforced form to increase dimensional stability or other properties, or for economy. Most formulations require heat and/or pressure for curing.

This phase of the study has attempted to bring together appropriate ASTM information in a systematic form, mainly for use in answering high-g inquiries. It is true that this type of assessment can be misleading and the selection criteria used may not be the most realistic in a given application. However, in the absence of actual experience, ASTM information is the best type of data available. If given the best reliable properties of each material under standard or known conditions, as a general rule the selection of the materials based on this information will probably be representative of the end-use applications.

Table I compares the relevant properties of each generic material that has been selected. These properties can be changed significantly by compounding the base resins with fillers, plasticizers, or reinforcements, or by copolymerizing them with other monomers.

Fillers usually decrease cost, increase stiffness, improve dimensional stability and reduce shrinkage. Plasticizers increase flexibility and reduce most strength properties. Most reinforcements improve strength, dimensional stability, and thermal endurance, and increase cost. Copolymers can have either higher or lower properties and cost depending on the monomers used and the percentage of each.

All molding processes alter ASTM published data-sheet properties, reducing most strengths and often creating areas of stress points. Sometimes, a processing method is so severe that there is no choice but to either redesign or change to a different material.

To make a first "best" material selection for high-g parts, the information in Tables I and II is a starting point.

VI. PROPOSED HARDWARE DESIGN AND DEVELOPMENT TASK

A. General

As stated in Sections IV.A and IV.H.5, experience must be gained to design and process successful high-g plastic parts. The objective of this proposed task is to acquire the knowledge and experience necessary to identify the right base resin and formulation to yield a composite material tailored to suit the requirements. With the price of composite materials declining steadily and researchers learning more about how to design and improve fabrication techniques, advanced composites seem to be on the threshold of becoming mainstay industrial materials. In some applications, composite materials are currently competing on cost alone with aluminum and other metals. Aerospace-grade epoxy/graphite now sells for about half the price it was five years ago. However, the current problem with composites is still mainly cost and processing techniques. Ultimately, the designer hopes to fabricate plastic parts, using improved resins that melt under pressure alone; thus, eliminating labor cost needed to form a complex metal structure of varying thicknesses.

B. Recommendation

It is recommended that the next step in the progression toward a feasible demonstration of high-g molded non-metal parts for an inertial instrument should include the following areas of work:

1. Investigate the design compatibility of using molded non-metal parts which are applicable to the compliant air bearing gyro design and the high-g gimbal platform.

2. Identify parts which area suitable for molding.

3. Initiate plastic part design layout.

4. Develop precision molding fabrication concepts and methodology.

5. Evaluate molded composite parts to determine if primary goals are achievable. Select and/or rank order composite materials which are best suited for the application.

6. Build a prototype high-g gyro design using the processing technology developed for the selected plastic subcomponents.

TABLE I. MATERIAL PROPERTIES (Ref 1,2,3,4,5,6,7,9,10)

GENERIC TYPE/FILLER, BLEND, GRADE, etc	ASTM	EPOXY/CYCLOALIPHATIC (TS)	MELAMINE FORMAL D/GLASS (TS)	MELAMINE FORMAL D/ALPHA CELLULOSE (TS)	MELAMINE FORMAL D/MACERATED FABRIC (TS)	POLY (AMIDE-IMIDE)/GENERAL PURPOSE	POLY (AMIDE-IMIDE)/GRAPHITE	POLY (AMIDE-IMIDE)/MINERAL	POLYIMIDE/GLASS	POLYPHENYLENE SULFIDE/GLASS (40%)
MECHANICAL PROPERTIES										
Tensile Modulus, 10^5 lb/in^2	D638	4.8-5	24	12-14	14-16				28	11
Elongation, % Break	D638	2-8		0.6-0.9	0.6-0.8	3-12	3-6	2-5	1	1
Tensile Str., Yield, 10^3 lb/in^2	D638	9-12	6-10	7.0-12.0	8.0-10.5	13.5-26.9	13.0-29.8	11.3-21.1	27.0	19.5
Impact Str., Izod Notched, ft lb/in	D256	0.2-1.0	2.0-18.0	0.25-0.35	0.6-1.0	1.0-2.5	0.8-1.2	0.5-1.4	17	0.8-1.5
Flexural Modulus, 10^5 lb/in^2	D790	4-5	20.0-27.0	11.0	14.0	6.6	7.0-25.9	11.0	33.0	17.0
Flexural Str., Yield, 10^3 lb/in^2	D790	12-13	15.0-22.0	10.0-16.0	12.0-15.0	23.0-30.7	22.0-45.9	21.0-30.7	50.0	29.0
Compressive Str., 10^3 lb/in^2	D695	30-50	20-25	40-45	30-35	32	34	47	32-33	21.0
Hardness	D785	M85-M120	M117-M125	M125-M155	M120	R104 M119	R98	R100	M120	M123
THERMAL PROPERTIES										
Continuous Service Temp., °F		450-500		210		500	500	500	500	450-500
Brittleness Temp., °F	D746									
Linear Thermal Expan., 10^{-5} in/in/°F	D696	1.6-3.0	1.5-1.7	4.0	2.4-2.8	2.0-3.5			1.5	2.2-4.0
Thermal Conductivity, BTU/in/hrft^2 °F	C177		3.3	2.0-3.2	3.1	1.7			3.1	2.0
Specific Heat, BTU/lb °F	C351			0.4						
Deflection Temp, at 264-psi, °F	D648	>200	440	360	400	525	531	518	660	>500
Flammability Class, UL 94 Test	D2863		V-0	V-0		V-0	V-0	V-0		V-0
ELECTRICAL PROPERTIES										
Volume Resistivity, ohm cm	D257	>1×10^{16}	1×10^{11}	1×10^{12}	1×10^{10}	1×10^{14}-1×10^{17}	3×10^{16}		1×10^{15}	1×10^{16}
Dissipation Factor, 50-100 Hz	D150	.006	.15-.25	.03-.08	.07-.30	.005-.007		.008	.003	.001
Dielectric Constant, 50-100 Hz	D150	3.4	10-11	8.0-9.5	7.5-12.0				4.8	3.9
Dielectric Str., V/10^{-3} cm	D149	400	170-300	270-300	250-350	600		625	500	450
Arc Resistance, Sec	D495	150-180	180-186	125-136	122-128	125			180	120
PHYSICAL PROPERTIES										
Density, g/cm^3	D792	1.22	1.8-2.0	1.4-1.5	1.5	1.4	1.4	1.8	1.9	1.64
Water Absorption, %-24 hrs	D570	0.9-0.7	0.9-0.2	0.1-0.6	0.3-0.6	0.3	0.3	0.2	0.2	0.00 <0.02
Chemical Resistance	D543						SEE TABLE II			
PROCESSING PROPERTIES										
Linear Mold Shrinkage, in/in	D955		.001-.004	.005-.010	.003-.004	.006	.005	.005	.001-.002	.002
Processing Temp., °F			280-335	280-360	275-350	650-725	650-725	650-725	380-450	600-650

TABLE II. CHEMICAL RESISTANCE (Ref 1,8)

	ALIPHATIC HYDRO-CARBONS	AROMATIC HYDRO-CARBONS	OILS, FATS WAXES	FULLY HALOGEN-ERATED HYDRO-CARBONS	PARTLY HALOGEN-ERATED HYDRO-CARBONS	ALCOHOLS MONO-HYDRIC	ALCOHOLS POLY HYDRIC	PHENOLS	KETONES	ESTERS	ETHERS	INORGANIC ACIDS CONC.	INORGANIC ACIDS DILUTE	BASES CONC.	BASES DILUTE	SALTS ACID	SALTS NEUTRAL	SALTS BASIC	ORGANIC ACIDS CONC.	ORGANIC ACIDS DILUTE	OXIDIZING ACIDS CONC.	OXIDIZING ACIDS DILUTE	SUNLIGHT & WEATH-ERING
EPOXY	EX	GOOD TO EX	EX	EX	GOOD	EX	EX	FAIR	FAIR	GOOD	FAIR	FAIR	EX	EX	EX	EX	EX	EX	FAIR	GOOD	POOR	FAIR	GOOD
MELAMINE FORMALDEHYDE	GOOD	GOOD TO EX	GOOD	EX	EX	EX	EX	GOOD	GOOD	GOOD	EX	POOR	FAIR	POOR	GOOD	EX	EX	GOOD	GOOD	GOOD	POOR	FAIR	GOOD
POLYAMIDE (NYLON)	GOOD	FAIR	GOOD	FAIR	POOR	GOOD	GOOD	POOR	GOOD	FAIR	GOOD	POOR	GOOD	GOOD	EX	POOR	GOOD	FAIR	POOR	FAIR	POOR	POOR	FAIR TO GOOD
POLYIMIDE	EX	EX	EX	EX	EX	EX	EX	GOOD	EX	EX	EX	FAIR	GOOD	POOR	FAIR	GOOD	GOOD	POOR	GOOD	EX	POOR	GOOD	EX
POLYPHENYLENE SULFIDE	EX	GOOD		FAIR	POOR	EX	EX	GOOD	GOOD	EX	GOOD	GOOD	GOOD	GOOD	EX	GOOD	GOOD	GOOD	GOOD	GOOD	POOR	FAIR	GOOD

REFERENCES

1. Desk-Top Data Bank, Book A, Plastics 1980, Condura Publications, Inc.

2. Desk-Top Data Bank, Book B, Plastics 1980, Condura Publications, Inc.

3. Desk-Top Data Bank, Supplement I, Plastics 1980, Condura Publications, Inc.

4. Desk-Top Data Bank, Specifications for Plastics, Condura Publications, Inc.

5. Desk-Top Data Bank, Plastics for Electronics, Condura Publications, Inc.

6. Desk-Top Data Basnk, Films, Sheets, and Laminates, Condura Publications, Inc.

7. Desk-Top Data Bank, Foams 1978,, Condura Publications, Inc.

8. RAPRA DATA HANDBOOK, The Chemical Resistance Data Book, Volumes I and II, Condura Publications, Inc.

9. Machine Design, 1980 Materials Reference Issue, Vol. 52, No. 8, A Penton/IPC Publication.

10. Military Standardization Handbook, MIL-HDBK-700(MR), 1 November 1965, Department of Defense, Washington, DC.

DISTRIBUTION

	No. of Copies
IIT Research Institute ATTN: DACIAC 10 West 35th Street Chicago, Illinois 60616	1
DRSMI-LP, Mr. Voigt	1
DRSMI-R, Dr. McCorkle	1
-RBD	3
-RPT (Reference Copy)	1
-RPT (Record Set)	1
-RG, Dr. Yates	1
-RGL, Mr. Clayton	1
-RGL, Mr. Rodgers	10
-RPR	15

FILMED

8-8